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LANSDALE DIVISION
Lansdale, Pennsylvania

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Lansdale, Pennsylvania

PEM for
TRANSISTOR MANUFACTURING
PROCESS IMPROVEMENT
Third Quarterly Progress Report
1 November 1962 to 31 January 1963
Contract No. DA-36-039-SC-86720
Placed by: USAEMA, Philadelphia, Pa.

Philco Project No. R-232.1

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PEM for TRANSISTOR MANUFACTURING PROCESS IMPROVEMENT

Third Quarterly Progress Report

Period Covered:

1 November 1962 to 31 January 1963

Contract No. DA-36-039-SC-86720

Placed by: USAEMA, Philadelphia, Pa.

Object of Study:

Production Engineering Measure (PEM) in accordance with Step 1 of Signal Corps Industrial Preparedness Procurement Requirements (SCIPPR) No. 15, dated 1 October 1958, for improvement of production techniques to increase the reliability for the Jet Etch Transistor type 2N501A, with a maximum operating failure rate of 0.01% per 1000 hours at a 90% confidence level at 25°C as an objective.

Philco Project No. R-232.1

Report prepared by J. Sanders

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SECTION I - ABSTRACT

The final design of the pilot line transistor is reported complete, with all process improvements as finally established installed on the pilot line. A production facility for manufacture of the improved transistor has been set up and is operating with all process improvements except hot sealing and leak determination.

Results from further work on the high thermal conductivity silver electrode system were not adequate to permit its use in the production process and, therefore, the nickel electrode system is being used. Evaluation of emitter and collector lead wires in various materials and diameters was completed, and 1.2-mil nickel plated silver and 2.5-mil silver have been specified for the emitter and collector lead wires, respectively.

Metagermanic acid treatment was definitely proven to be detrimental to the transistor structure used, and no surface treatment is specified for the collector side. Hydrogen peroxide treatment of the emitter side has been specified as the result of demonstrated merit in stabilizing both V_{EB} and h_{FE}.

Modifications were made to the prototype encapsulating equipment and good repeatability of fill is reported.

Continued testing has verified the slope of the failure rate curve as proposed in the Second Quarterly Report. Further testing is also reported in connection with determination of thermal resistance. The continuous d-c V_{EB} method has shown capability of giving a value in close agreement with the effective thermal resistance of the transistor.

Pilot line transistors, both with and without black painting, were evaluated with regard to thermal dissipation. The improved thermal dissipation and, therefore, increased operating capability of the black painted units was demonstrated. Black painting has been specified for the transistor.

Status of the Inspection and Quality Control Plan and of the Chemical Control Program are reported, with completed items enumerated.

SECTION II - PURPOSE

The purpose of this contract is to improve production techniques to increase the reliability of transistor type 2N501A (or of additional or substitute transistors as specifically authorized by the Contracting Officer). An objective is a maximum operating failure rate of 0.01% per 1000 hours at a 90% confidence level at 25°C. This failure rate is an objective and, as a minimum, all process improvements listed below will be performed toward attaining or exceeding it.

Processes to be Improved*

a. Plating Edge Definition

b. Higher Temperature Alloys

c. Lead Attachments (includes collector attachments)

d. Gettering Techniques for Encapsulating and Sealing

e. Thermal Dissipation of Package

f. Leak Determination

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* Controlled Formation of Surface Oxides for Surface Stabilization, listed in previous quarterly reports, has been deleted as a result of process improvements implemented in accordance with USAEMA approval of Technical Action Request No. PL-1, dated 8 October 1962.

The process improvements will be incorporated in a production run for final test, and the data obtained will be consolidated and presented in accordance with Part 1 of the ASTM Manual on Quality Control of Materials, January, 1951.

Performance of the contract also calls for the delivery of the following items:

1. Engineering Samples (48 each)
2. Quarterly Reports (75 copies/qtr)*
3. Final Engineering Report (75 copies)*
4. Bills of Materials and Parts (2 copies) (Forms DD346 and DD347)
5. General Report on Step II (6 copies) (Twice the maximum rate attainable with existing facilities).

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* Quantities increased from 50 to 75 in accordance with changes to Contract Sub-Items 5-2 and 5-3 made by Modification No. 1, dated 9 January 1963.

SECTION III - NARRATIVE AND DATA

3.0 General (J. G. Sanders)

Final design of the pilot line transistor was completed during this quarter and all process improvements, in their final form, have been installed. Prior to installation of the hot sealing equipment on the pilot line, a sample of 500 transistors was taken from the line for operating, storage, and environmental testing. These tests are currently in progress. A second sample of 500 transistors, incorporating the hot sealing process, is currently being accumulated. Tests performed on the first and second samples will be identical.

A production facility for manufacturing the transistor designed on the pilot line has been set up in the factory under the supervision of the Preproduction Engineering Department. This line is currently in operation and has all of the process improvements except hot sealing and leak determination. Samples from the line are being evaluated by the Reliability and Quality Control Department as part of a standard qualification procedure prior to release for general sale.

Specific work accomplished during this quarter is described in the following subsections.

3.1 Process Improvements

3.1.1 Silver Collector Electrode (J. Javes)

Previous work under this program has shown that improvements in the thermal conductivity of the collector contact can be achieved by using a high-thermal-conductivity electrode such as silver. Further work was performed this quarter with emphasis on improving the plating characteristics of the silver electrode system so that the process would be more compatible with production.

The plating characteristics desired of the silver system are:

1. Small grain size
2. Controllable thickness of electrode
3. Controllable diameter of electrode
4. Good edge definition
5. Good adhesion at the silver-germanium interface
6. Short plating time (3 seconds or less).

From the preliminary work it had been determined that the two most practical systems were the fluoborate system and the cyanide system. Subsequent work with the fluoborate system showed serious problems due to immersion plate or poor adhesion and the use of this system was discontinued.

The effect of additives on the plating characteristics of the cyanide system were studied. Among these additives were thiourea, turkey red oil, orthoaminobenzenesulfonic acid, white glue, Silverex Brightener, Silver Lume Brighteners "A" and "B", dextrose, gelatin, potassium carbonate, nickel fluoborate, acetic acid, trisodium phosphate, sodium carbonate, potassium hydroxide and Ultrawet DS solution.

From these tests it was concluded that gelatin, potassium carbonate, potassium hydroxide, and Ultrawet DS solution gave desirable improvements in one or more plating characteristics; however, problems involving adhesion and length of plating time were still evident. In particular, a cyanide system which evolved as a result of the study still required 25 seconds to plate an electrode of the desired size and thickness. Bath modifications, centering chiefly on ways to increase the silver ion concentration or plating rate, gave some improvement, but were not successful in reducing the plating time to the desired three seconds.

In tests where a fixed time was allotted for the silver plating step, and other variables changed, the cyanide system was not capable of achieving the desired thickness and density of plate. In addition, considerable sacrifice of diameter control was necessary to obtain higher deposition rates.

Although the idea of a high-thermal-conductivity collector electrode has proven merit, the problems and compromises associated with turning this into a production process would give a low probability of success in the time remaining. Consequently, no further work on this section of the program will be scheduled. The transistor will be put into production with the nickel collector electrode system described in previous reports.

3.1.2 Emitter and Collector Lead Wires (A. McKelvey)

In determining the final design of the pilot line transistor, different emitter and collector lead wires were evaluated. This evaluation was concerned with determining the right combination of lead diameter and lead material consistent with the following requirements.

1. Good thermal conductivity
2. Resistance to environmental stress
3. High fabrication yields.

Units were fabricated, over a period of several weeks, using the various emitter and collector wire combinations listed below. Other fabrication processing steps were the same for all groups.

Group	Emitter Wire	Collector Wire
A	0.001" Gridnic	0.0025" Ag
B	0.001" Ag	0.0025" Ag
C	0.001" Ni plated Ag	0.0025" Ag
D	0.0015" Ag	0.0025" Ag
E	0.0012" Ni plated Ag	0.0025" Ag
F	0.0012" Ni plated Ag	0.003" Ag

Comparative thermal conductivities of the various wires were determined from high stress operating life results and are shown in Table 3-1.

3.1.2.1 Emitter Wire

Although the thermal-resistance-to-case measurements by the I_{CBO} method showed no difference between groups A or B above (θ = 0.216°C/mw for both groups), a most significant difference was seen in the high-stress operating-life results. The 1.0-mil Gridnic wire group shows 0% survival after a 16-hour stress at 350 mw, compared to 50% survival for the 1.0-mil silver wire group after a 32-hour stress at the same operating level. However, units fabricated with 1.0-mil silver emitter wire failed to meet minimum environmental requirements. Specifically, failures in the form of broken emitter wires after 20K"G" centrifuging were observed. In an attempt to strengthen this failure point, nickel plated silver wire was substituted for the pure silver wire. Operating stress data evaluating this change (Groups B, C) show that the thermal properties of the 1.0-mil pure silver wire are superior to those of the 1.0-mil nickel plated silver wire. This could not be attributed to wire composition, since electrical resistivity measurements of the two wires (even after extended high temperature bakes) showed them to be equivalent. Consequently it was concluded that the nickel plating acted as a heat barrier and hindered the flow of heat from the silver wire to the surrounding encapsulant within the package, thereby reducing the efficiency of the wire in removing heat from the junction area.

Tests with larger diameter wires (1.2- and 1.5-mil) were conducted with the conclusion that the 1.5-mil wire was not compatible with the emitter electrode size that had to be maintained for this device. Mechanical shrinkage in the form of emitter solder separation from the plated emitter electrode made this wire impractical for production use. The 1.2-mil wire was shown to be satisfactory for production use, and subsequent evaluation of units fabricated using 1.2-mil nickel plated silver wire on operating stress (Group E) showed this wire to be comparable to 1.0-mil pure silver wire for thermal conductivity. In addition, environmental tests (20K"G" centrifuge) were conducted with the results shown in the accompanying table.

Emitter Wire	# Units Tested	Open Emitter	% Failures
1.0-mil Ag	100	2	2.0
1.0-mil Ni plated Ag	328	5	1.52
1.2-mil Ni plated Ag	1061	2	0.188

3.1.2.2 Collector Wire

Tests were run to determine feasibility of fabricating this device using a 3-mil silver collector wire. A significant improvement was seen in the % survival after operating stress on units incorporating this wire (Group F). High mechanical shrinkage, particularly in the form of cracked germanium webs precluded the use of 3-mil diameter silver collector wire on this device. The use of 3-mil silver wire resulted in 16.9% shrinkage for cracked webs over a period of nine days. Control units using 2.5-mil silver wire showed 2.8% shrinkage for this item over a period of four weeks.

3.1.3 Metagermanic Acid (A. McKelvey)

As reported in the Second Quarterly Progress Report, metagermanic acid is not chemically compatible with the low-resistivity p-type surface of the diffused collector structure and has been removed from the pilot line process. Collector-base diode stability of a diffused junction transistor is superior to that of a surface formed abrupt juction transistor, such as the MADT, and surface treatments to enhance the stability of the diode are not required. Data substantiating this argument were accumulated during this quarter and are contained in Table 3-2. These data show conclusively that metagermanic acid causes softening of the diode in this type of structure and is, in fact, detrimental to device yield. In view of these results, no surface treatment for the collector side of the pilot line transistor has been specified. Hydrogen peroxide treatment of the emitter side will remain a part of the process because of its merit in stabilizing both V_{EB} and h_{FE}.

3.1.4 Hot Sealing Oven (K. Hales)

Construction of the hot sealing oven was completed during this quarter. Preliminary check-out of the oven indicated satisfactory operation except for a high temperature gradient between the extreme ends of the oven. Modifications to reduce this gradient were undertaken and included:

1. Shifting a number of the heating elements to the colder end of the muffle,

2. Increasing the pitch of the blower fan,

3. Adjusting the position of the blower fan to increase the clearance between the fan and the end of the oven,

4. Increasing the size of the openings at both ends of the dividing plate.

These modifications were successful in reducing the gradient to an acceptable level and the oven was subsequently installed in the pilot line. Transistors are currently being processed through the oven for evaluation in operating, storage, and environmental life tests.

3.1.5 Black Painting (A. McKelvey)

Black painting as a final finish is standard practice on a number of transistor types currently in production. Black painting improves transistor emissivity on operating life, and consequently improves the thermal dissipation of the package.

In a test during this quarter, pilot line transistors were used in comparing black painted units against control units for performance on high stress operating life.

The test data, contained in Tables 3-3A and 3-3B, can be summarized as follows:

1. The thermal resistance factor to air (θ_{J-A} by the I_{CBO} method) showed the black painted units to be 13.6% lower than the non-painted units,

2. The units were stressed for 48 hours at 350 mw; 93.5% of the non-painted units failed this test, as opposed to the failure of only 26.5% of the black painted units.

In view of these results, the standard factory black painting process has been specified for this transistor.

3.1.6 Encapsulant Dispensing Equipment (C. Bayha)

Modifications to the prototype encapsulant dispensing equipment (previously reported as unsatisfactory with regard to the repeatability of fill) were completed during this quarter. These modifications included:

1. Installation of larger cylinder on metering piston.
2. Addition of adjustable stop on metering piston to control quantity of compound dispensed.
3. Enlarging the ports in the dispenser for easier flow of compound.
4. Relocation of cycling switch to gain more accurate filling for dispensing.
5. Redesign of reservoir to minimize oil separation.
6. Construction of compound pump to load reservoir cartridges to eliminate entrapment of air.

7. Redesign of mount for more operating accessibility.

8. Redesign of cartridge holder for easier and more dependable cartridge change.

9. Supply of five (5) reservoir cartridges.

Data accumulated after completion of the modifications indicate the equipment is now dispensing encapsulant to a consistency of ±2% of the desired weight. This is considered satisfactory and the equipment has been released for use in the production facility that is fabricating the improved transistor.

3.1.7 Leak Determination (A. McKelvey)

Testing of the pilot line transistor by both the helium bomb method and the wet bomb method has continued through this quarter. Results of this testing are 17 wet bomb failures of 2625 transistors tested and 6 helium bomb failures of 1300 transistors tested, for an overall failure rate of 1.2%. Helium bomb failures are adjudged to be failures to the sensitivity of the mass spectrometer equipment, which is stated to be an apparent leak rate of 5×10^{-10} cc/sec.

3.2 Inspection and Quality Control Plan (E. Wojcik)

Preparation of the Inspection and Quality Control Plan is proceeding on schedule. Rough drafts of the following specifications have been completed.

1. Processing Flow Chart
2. Incoming Materials Inspection Specification
3. Process Control Inspection Specification
4. Quality Control Acceptance Specification.

Upon completion of the Equipment Specification, the Plan will be complete and will be reviewed with the USAEMA.

3.3 Chemical Control Program (E. Cocozza)

The following specifications relating to the control of chemicals to be used in processing the production transistor were completed and issued during the third quarter.

1. Standard Material Specifications and Quality Acceptance Specifications

   SMS T-32 Silicone Fluid

   SMS T-33 Lithium Chloride, Granular, Reagent

   SMS T-34 Citric Acid, Crystals, Reagent

   SMS T-35 Ammonium Nitrate, Granular, Reagent

SMS T-36 Glycerin, Reagent

SMS T-37 Xylene, Reagent

SMS T-38 Ammonium Chloride, Crystals (or granular), Reagent

SMS T-39 Zinc Oxide, Reagent

SMS T-40 Cadmium Chloride, Anhydrous, Reagent

SMS T-41 Zinc Chloride, Granular, Reagent

SMS T-43 Acetic Acid, Glacial, Reagent

QAS T-45 Boron Nitride Potting Compounds

SMS T-47 Hydrogen Peroxide (30%), Reagent

SMS T-48 Boric Acid, Reagent

SMS T-50 Sodium Fluoride, Anhydrous, Reagent

SMS T-51 Manganese Sulfate Monohydrate, Reagent

SMS T-53 Hydrofluoric Acid (49%), Semiconductor Grade

SMS T-54 Sulfuric Acid, Reagent.

2. Analytical Specifications

A. Boron Nitride Powder

PS-AN-B-200: Determination of Chloride

PS-AN-B-201: Determination of Sulfate

PS-SL-B-101: Determination of Trace Metals

PS-AN-A-206: Determination of pH

B. Silicone Fluid and Encapsulating Compound

PS-AN-P-204: Determination of Electrical Volume Resistivity

C. ACS Tests

PS-AN-Z-201: Zinc Oxide, ACS Tests

PS-AN-Z-202: Zinc Chloride, ACS Tests

PS-AN-C-208: Cadmium Chloride, ACS Tests

D. Boron Nitride - Epoxy Coating Solution

PS-AN-E-100: Flake Test

E. Hydrofluoric Acid

PS-SL-H-200: Determination of Trace Metals

3. Processing Specifications

A. PS-C-233: Boron Nitride Potting Compound Preparation

B. PS-C-234: Boron Nitride - Epoxy Coating Solution.

3.4 Pilot Line Testing (J. Sanders)

Evaluation of the final design of the pilot line transistor will take place during the next quarter. Two 500-transistor lots will be drawn from the line for testing. One of the lots will feature all process improvements; the other lot will also have the process improvements except for sealing without being processed through the hot sealing equipment. The transistors will be submitted for testing as follows:

100 units - 250-mw operating life

100 units - 150-mw operating life

100 units - 175°C storage life

100 units - 125°C storage life

100 units - environmental test.

The test data will be used to estimate attained reliability of the pilot line device.

A failure analysis on all reject units will be completed by the Quality Control Assurance Group and reported on the form of Table 3-4. Information from these analyses will be applied to the production process.

3.5 Thermal Resistance (J. McKenney)

From data accumulated during the second quarter, and reported in the Second Quarterly Report, it has been determined that the effective thermal resistance of the pilot line transistor is about 0.6°C/mw. Attempts to obtain this number by direct measurements have in general been unsuccessful.

During this quarter, work was continued with emphasis on V_{EB} (emitter-base forward voltage drop) as the temperature sensitive parameter.

Construction of the new V_{EB} method test set, designed for fast sampling with a maximum lag of 10 µsec between the power and reading cycles, was completed. Subsequent evaluation of transistors by the V_{EB} method, and by the I_{CBO} method, showed that the thermal resistance to case measurement obtained by the V_{EB} method, by the I_{CBO} method, and by the V_{EB} method with power applied at T_{HIGH} was the same (about 0.2°C/mw).

A comparison of the pulsed V_{EB} method to case (with about 80 mw applied at the high temperature) with the continuous d-c V_{EB} method of measurement is contained in Table 3-5. These data show that the d-c method yields a figure about 32% higher than that obtained by the pulse method. Initial attempts to establish a measurement to air were unsuccessful due to extremely erratic readings. This problem was overcome by the addition of a split contact socket to the system to reduce series resistance. Thermal-resistance-to-air measurements are contained in Table 3-6 and show a figure of about 0.54°C/mw for the d-c method as compared with 0.43°C/mw for the pulsed method. This figure is in close agreement with the effective thermal resistance of the device.

Constant power curves of thermal resistance by the continuous d-c V_{EB} method measurement versus I_E have been plotted and are shown in Figure 3-1. These curves are reasonably linear with current, and show a wide range of bias conditions over which this test can be used.

When measuring thermal resistance by continuous d-c methods, errors are introduced because the temperature sensitive parameter, in this case V_{EB}, is affected by the change in bias conditions when going from the high to the low temperature. For example, for case measurements at a constant current of 50 mA, typical conditions would be:

$T_{High} = 55°C$

$T_{Low} = 30°C$

$P_{T_{Low}} = 80$ mw (1.6V and 50 mA)

$P_{T_{High}} = 172.5$ mw (3.45V and 50 mA).

Thus

$$\theta = \frac{T_{High} - T_{Low}}{P_{T_{Low}} - P_{T_{High}}} = \frac{55°C - 25°C}{172.5mw - 80mw} = 0.27°C/mw,$$

and it can be seen that the change from T_{High} to T_{Low} requires a voltage increase of about 2V.

By measurements of change in V_{EB} due to change in V_{CB}, it has been determined that for a ΔV_{CB} of 2V, the ΔV_{EB} is about 7 mv. Since V_{EB} changes at the rate of 2 mv/°C, 7 mv can be interpreted as a temperature error of 3.5°C, and the corrected θ would be:

$$\theta = \frac{T_{High} - T_{Low} - T_{Corr}}{P_{T_{Low}} - P_{T_{High}}} = \frac{55°C - 25°C - 3.5°C}{172.5\ \text{mw} - 80\ \text{mw}}$$

$$= 0.232°\text{C/mw}.$$

This number is somewhat lower than the effective thermal resistance of the device, but is more in agreement than that obtained by pulse methods of measurement.

3.6 Incorporation of Process Improvements in Production Line

(J. G. Sanders)

During this quarter a production line was set up in the factory, under the supervision of the Preproduction Engineering Department, for the purpose of manufacturing the transistor designed on the pilot line. All process improvements, except hot sealing and leak determination (helium bomb method), have been incorporated into the production line. The Reliability and Quality Control Department is currently sampling the output of the line as part of a standard procedure of qualifying the device for general sale. Data available from this testing is presented in Table 3-7. The endpoint criteria used to determine failure are:

I_{CBO} at V_{CB} = -6V..................-6μA max.

V_{CB} at I_C = -100 μA..............-12V min.

h_{FE} at V_{CE} = -0.3 V

and I_C = -10 mA............... 20 min.

A plot of the operating failure rate data is contained in Figure 3-2. The slope of this curve is in reasonable agreement with the slope of the proposed curve as given in the Second Quarterly Report.

Examination of the storage life data of Table 3-7 shows no rejects to the designated endpoints listed above. However, some beta change did occur on storage life and a plot of these changes is shown in Figure 3-3. Specifically, the plot is ΔI_B from 0 to 1000 hours of life for 100 units at each of the three storage temperatures (100°C, 125°C, and 150°C). By selecting an arbitrary endpoint to force one failure in the low temperature group it was possible to construct the failure rate curve shown in Figure 3-3. The slope of this curve is also in good agreement with the slope of the proposed curve as described in the Second Quarterly Report.

SECTION IV - CONCLUSIONS

1. Although a high-thermal-conductivity silver collector electrode has proven merit, not enough time remains to turn this system into a satisfactory production process. Consequently, the transistor will be put into production with the nickel electrode system described in previous reports.

2. An evaluation of emitter and collector lead wires has been completed and specific wires compatible with the objectives of this program have been specified for the production transistor.

3. An evaluation of metagermanic surface treatment has been completed. No benefit to diode stability was demonstrated; in fact, it was determined that metagermanic acid is detrimental to yield for this type of device.

4. The hot sealing oven has been installed and is operating satisfactorily.

5. Black painting as a final finish has been shown to improve the operating capability of the pilot line device and has been specified for this transistor.

6. Modifications of the encapsulant dispensing equipment have been completed; the equipment is operating satisfactorily and has been turned over to the production facility.

7. Evaluation of the thermal resistance measurements by the continuous d-c V_{EB} method has shown that a value in close agreement with the effective thermal resistance of the transistor can be obtained.

8. Verification of the slope of the failure rate curve, as proposed in the Second Quarterly Report, has been obtained. This verification was obtained on production run transistors equivalent to the type being manufactured in conjuction with this program.

SECTION V - PROGRAM FOR THE NEXT INTERVAL

1. Complete installation of all process improvements in the production line.

2. Complete the Inspection and Quality Control Plan and submit to the USAEMA for review and approval.

3. Complete evaluation of the pilot line transistor and determine attained reliability.

4. Complete the Chemical Control Program.

SECTION VI - PUBLICATIONS, REPORTS AND CONFERENCES

No publications, lectures, or reports pertaining to work developed on this contract were issued or given during the period covered by this report.

One conference pertaining to the contract was held during the quarter covered by this report. The conference was held on 15 January 1963 at facilities of the Philco Corporation, Lansdale Division, in Lansdale, Pennsylvania, with representatives of the USAEMA and of the Philco Corporation in attendance.

SECTION VII - IDENTIFICATION OF PERSONNEL

The key technical personnel who have taken part in the work covered by this report are listed below and the approximate hours of work performed by each is given. Total approximate man-hour figures are also given for three general categories of technical assistance furnished to the key personnel during the quarter. Background resumes are included for three key individuals added to the program during the quarter.

Name	Approx. Man-Hours
Bayha, C.	10
Cocozza, E.	272
Hales, K.	37
Javes, J.	324
McKelvey, A.	482
McKenney, J.	130
Sanders, J.	313
Wojcik, E.	218
Total	1786
Misc. Engineering	697
Technicians and Operators	4540
Draftsmen and Model Makers	263

WOJCIK, EDWARD S. - Statistical Engineer

Mr. Wojcik received his B.S. in Statistics and Mathematics from Alliance College. He has been employed by Philco since 1960 as a Statistical Engineer in the semiconductor division. Prior to his employment at Philco, he was associated with Henkels and McCoy, Contractors, in design and development work. As Assistant Operations Sergeant in the U.S. Armored Cavalry he developed, organized, and conducted troop training programs.

McKENNEY, JAMES E. - Engineer

Mr. McKenney received his B.S. in Electrical Engineering from the University of Delaware in 1959. He joined the Lansdale Division of Philco Corporation upon graduation and has worked on evaluation of various semiconductor devices under development. Currently he is working on thermal resistance problems arising in the reliability improvement program. He is a member of the I.E.E.E.

HALES, KENNETH R. - Project Engineer

Mr. Hales received his B.S. in Mechanical Engineering from Drexel Institute of Technology in 1937. Prior to joining Philco in 1951 he has worked at the United State Gauge Co. on manufacturing equipment, and at Western Electric Co. on design and fabrication of transistor and tube production equipment. At the Lansdale Division of Philco he has served as supervisor of design with the Equipment Operation, where he has worked on the design and building of much of the automatic equipment used in semiconductor device and tube production. Among his activities were the development of spot plating machinery for A.M.P., the Automatic Transfer Machine for Philco's FAST Line, and multi-unit sputtering equipment. He holds two patents, for cold welding and packaging, related to transistor fabrication.

APPENDIX - TABLES AND FIGURES

TABLE 3-1

Operating Life Results for Units with Various Emitter and Collector Wire Combinations

Group	Emitter Wire	Collector Wire	Hours	# Units	I_{CO} -20V	h_{FE} -50mA	N	% Survival
A	0.001" Gridnic	0.0025" Ag	16	50	50	--	0	0
B	0.001" Ag	0.0025" Ag	16 32	30 24	6 9	-- --	24 15	50
C	0.001" Ni plated Ag	0.0025" Ag	16 32	45 35	10 15	-- 5	35 15	33
D	0.0015" Ag	0.0025" Ag	No Units Available for Submission				--	--
E	0.0012" Ni plated Ag	0.0025" Ag	16 32	20 17	1 1	2 4	17 12	60
F	0.0012" Ni plated Ag	0.003" Ag	16 32	14 13	-- --	1 --	13 13	93

Operating Stress: V_{CB} = -5V, I_C = -70mA

TABLE 3-2

Yield Comparison of Metagermanic Acid Treated Units With Non-treated (Control) Units Through Normal Stabilization Bake.

	No. Units	Median Values			No. Failures	% Failures
		V_{CB} I_C = -100μA	I_{CBO} V_{CB}= -6V	I_{CBO} V_{CB}= -20V		
Metagermanic Acid Treated Units	40	19	0.4	80.0	25	62.5
Control Units	69	28	0.4	0.6	10	14.5

TABLE 3-3

Comparison of Black Painted and Non-painted Units for
A. Thermal Resistance Factor to Air, and
B. Operating Stress.

A. Thermal Resistance Factor to Air, θ_{J-A}, I_{CBO} Method (°C/mw)	
Black Painted	Non-painted
0.443	0.524
0.454	0.495
0.464	0.504
0.434	0.450
0.434	0.504
0.379	0.504
0.460	0.471
0.444	0.504
0.433	0.464

B. 350 mw Operating Stress				
Condition	No. Units	Hours	Accumulative Failures	% Failures
Black Painted	15	16 32 48	0 2 4	26.5
Non-Painted	15	16 32 48	2 8 14	93.5

TABLE 3-4.

FAILURE ANALYSIS REPORT

TYPE ________ PACKAGE ________ FAMILY ________. LOT NO. ________

DATE OF FAILURE ________________ HOURS AT FAILURE ________________

TEST CONDITIONS ________________ SAMPLE SIZE ________________

FAILURE REPORTED AS -

____

FAILURE VERIFICATION - (On test set and by operator differing from original rejection)

VISUAL APPEARANCE - (Case, glass, leads) -

CATASTROPHIC FAILURES -

1. X-ray (3 views) -
   - a. Broken blank ☐
   - b. Open element ☐
   - c. Burn-out ☐
   - d. ________ ☐

2. Diode breakdown test -
   - a. Near short ☐
   - b. Direct short ☐
   - c. Remove top shield (examine at 60X)
     1. Solder deform ☐
     2. Solder flow ☐
     3. ________ ☐
   - d. Dissolve solder (examine at 425X)
     1. Fused areas ☐
     2. Holes thru ☐
     3. ________ ☐

DEGRADATION FAILURES -

1. ICBO, IEBO
   - a. He leak test — leak ☐ tight ☐
   - b. Remove top shield
     - 2 hr. bake (^{o}C) ☐
     - Improve ☐ No change ☐
   - c. Examine 60X
     1. Solder deform ☐
     2. Solder flow ☐
     3. ________ ☐

2. Other -

SPECIFIC FEATURES NOTED -

CAUSE OF FAILURE -

ANALYSIS BY ________________

TABLE 3-5

Comparison of Thermal Resistance to Case by the V_{EB} Method: Pulsed vs. Continuous D-C Measurements.

Unit No.	Pulsed V_{EB} Method °C/mw 80 mw at T_{HIGH}	D-C V_{EB} Method °C/mw
132	0.196	0.268
133	0.191	0.296
135	0.188	0.260
136	0.199	0.288
137	0.206	0.258
138	0.214	0.280
139	0.193	0.253
140	0.209	0.255
142	0.216	0.300
143	0.206	0.258
144	0.213	0.270
145	0.223	0.281
146	0.224	0.286
147	0.209	0.255
148	0.216	0.288
200	0.196	0.284
202	0.209	0.253
203	0.202	0.272
204	0.213	0.229
205	0.185	0.291
High	0.224	0.300
Low	0.185	0.229
Average	0.205	0.271

TABLE 3-6

Comparison of Thermal Resistance to Air by the V_{EB} Method: Pulsed vs. Continuous D-C Measurements

Unit No.	Pulsed V_{EB} Method °C/mw 30 mw at T_{HIGH}	D-C V_{EB} Method °C/mw
473	0.423	0.540
474	0.407	0.524
475	0.423	0.538
476	0.399	0.552
477	0.427	0.511
478	0.450	0.559
479	0.425	0.561
480	0.425	0.557
High	0.450	0.561
Low	0.399	0.511
Average	0.425	0.543

TABLE 3-7

Operating and Storage Life Data
on Units from Production Line

Group No.	Test Condition	No. Units	Test Hours	Failures ICBO $V_{CB}=-6V$	Failures VCB $I_C=-100\mu A$	Failures hFE $V_{CE}=-0.3V$ $I_C=-10mA$
Q3009A	150 mw	40	2000	0	0	0
Q3009B	150 mw	20	2000	0	0	0
Q3009C	150 mw	140	2000	1	1	0
Q3010A	200 mw	35	2000	0	1	0
Q3010B	200 mw	50	2000	1	1	1
Q3010C	200 mw	15	2000	0	1	0
Q3011A	250 mw	35	2000	0	3	1
Q3011B	250 mw	45	2000	0	4	3
Q3011C	250 mw	20	2000	0	2	0
Q3015A	150 mw	50	1000	0	0	0
Q2007A	125°C	20	2000	0	0	0
Q2007B	125°C	35	2000	0	0	0
Q2007C	125°C	45	2000	0	0	0
Q2008A	100°C	40	2000	0	0	0
Q2008B	100°C	160	2000	0	0	0
Q2009A	150°C	35	2000	0	0	0
Q2009B	150°C	50	2000	0	0	0
Q2009C	150°C	15	2000	0	0	0
Q2011	150°C	55	1500	0	0	0
Q2012A	100°C	55	1000	0	0	0

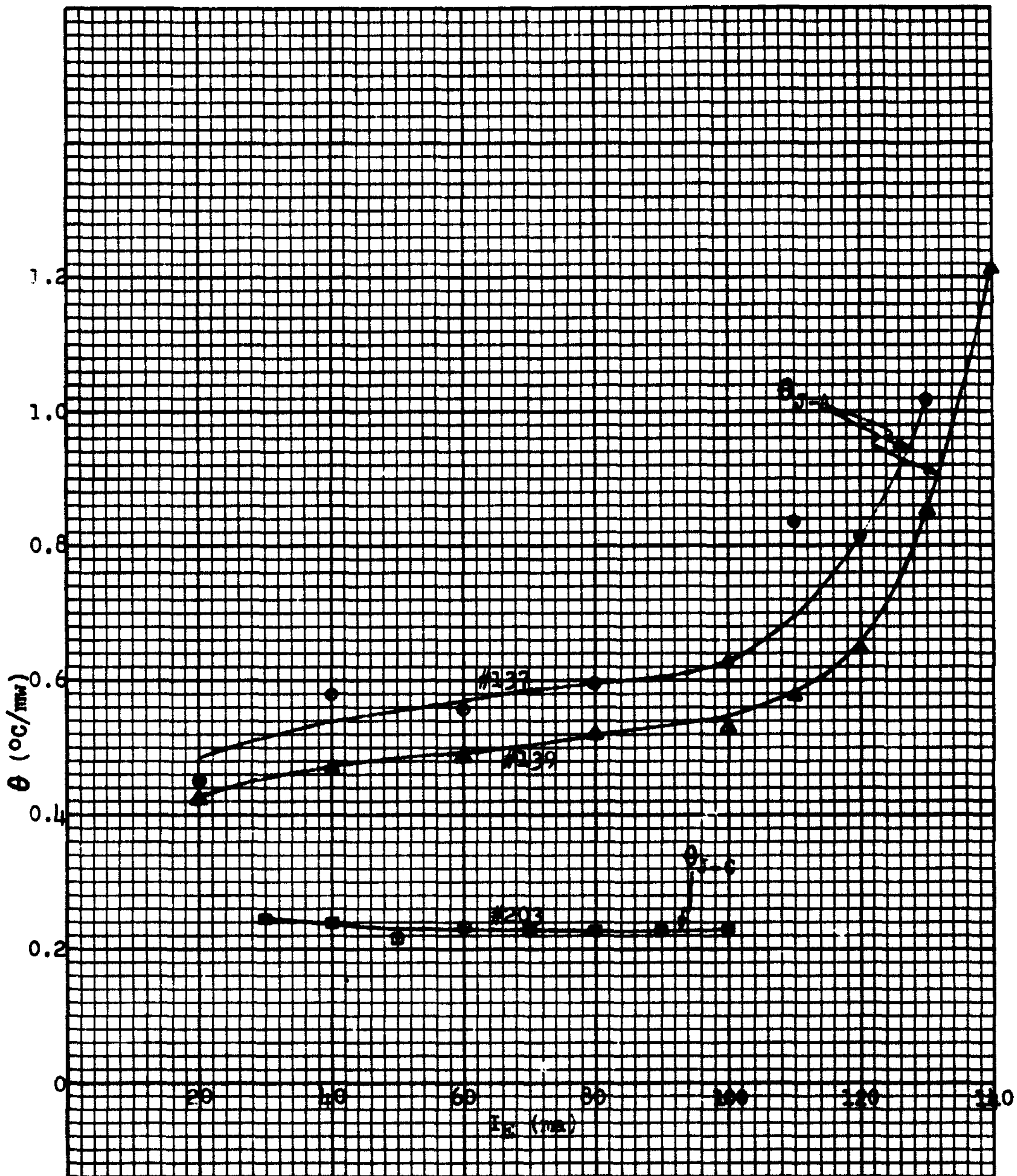

Figure 3-1. Constant Power Curves - Thermal Resistance Measurement by Continuous D-C V_{EB} Method vs. I_E

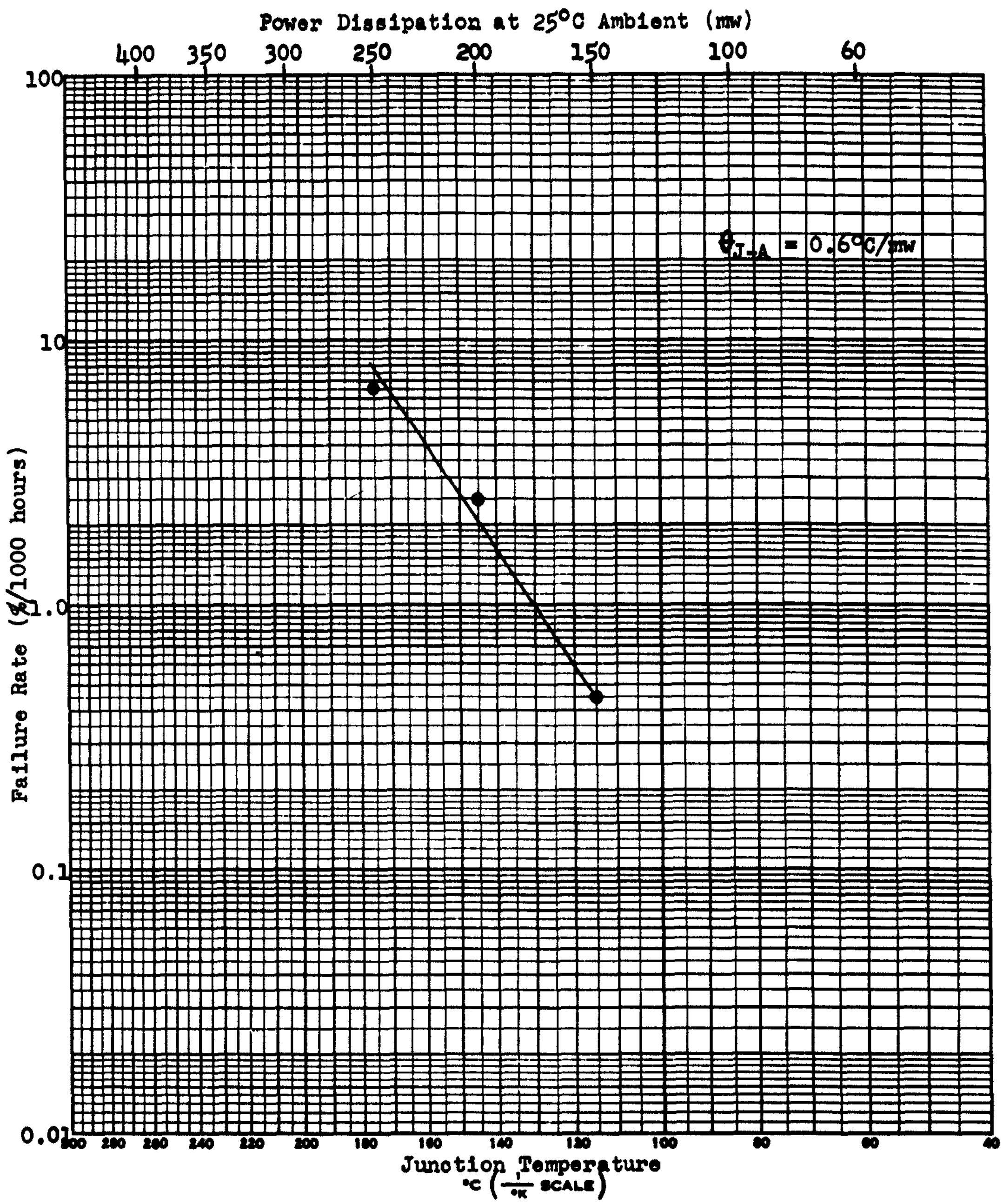

Figure 3-2. Observed Failure Rate Curve for Production Transistors

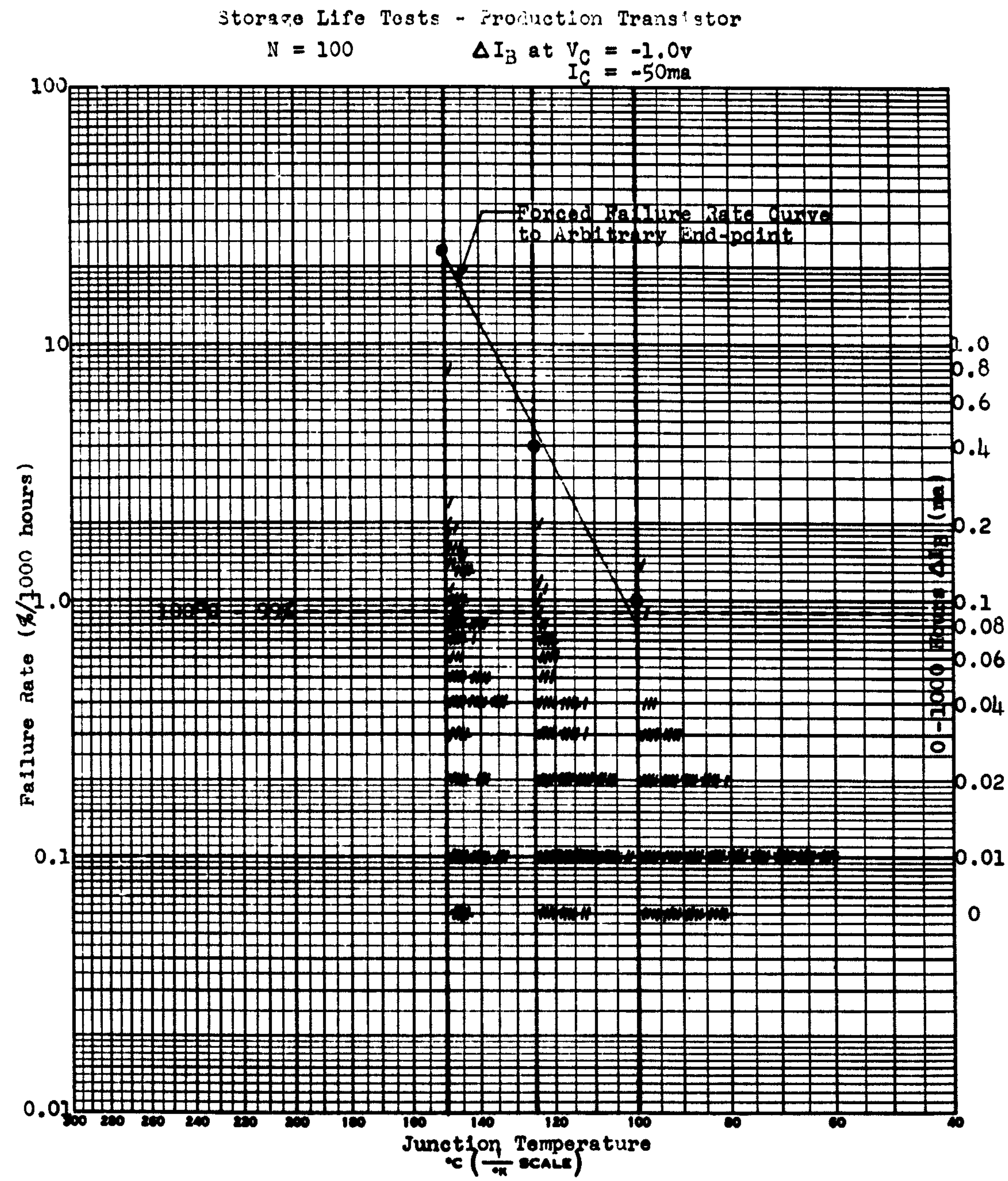

Figure 3-3. Plot of ΔI_B from 0 - 1000 Hours for Storage Life Tests of Production Transistor